

Research Article

Cocconeis crisscrossis sp. nov., a new monoraphid diatom (Bacillariophyta) from southern China

Huiwen Zhou¹, Pan Yu², Luyi Guo¹, John Patrick Kociolek³, Quanxi Wang¹, Qingmin You¹

¹ College of Life Sciences, Shanghai Normal University, Shanghai 200234, China

² College of Environmental and Geographical Sciences, Shanghai Normal University, Shanghai 200234, China

³ Museum of Natural History and Department of Ecology and Evolutionary Biology, University of Colorado, UCB 218, Boulder CO80309, USA

Corresponding author: Qingmin You (youqm1117@shnu.edu.cn)

Abstract

A novel monoraphid diatom species, *Cocconeis crisscrossis* You, Yu, Kociolek & Wang, **sp. nov.** is examined and described from the Qingyi River and Maolan Nature Reserve of southern China. The morphological description is based on light microscopy and scanning electron microscopy observations and the new species is compared with similar taxa in this genus. The characteristics unique to *Cocconeis crisscrossis* **sp. nov.** include its central area extending irregularly to both sides, it having closed valvocopulae with heavily silicified fimbriate margins and poles of the valvocopulae have ‘sword-shaped’ siliceous extensions. These features differentiate this new species from others in the genus. This new species was found in alkaline waterbodies, including streams, waterfall and ponds. It was usually found as an epiphyte on the stones; however, it was present on other substrates such as mosses.

Key words: diatoms, monoraphid, morphology, new taxa, taxonomy



Academic editor: Kalina Manoylov

Received: 18 March 2024

Accepted: 23 April 2024

Published: 13 May 2024

Citation: Zhou H, Yu P, Guo L, Kociolek JP, Wang Q, You Q (2024) *Cocconeis crisscrossis* sp. nov., a new monoraphid diatom (Bacillariophyta) from southern China. PhytoKeys 242: 39–50. <https://doi.org/10.3897/phytokeys.242.123316>

Copyright: © Huiwen Zhou et al.

This is an open access article distributed under terms of the Creative Commons Attribution License (Attribution 4.0 International – CC BY 4.0).

Introduction

The first described genus of Cocconeidaceae Kützing was *Cocconeis* Ehrenberg (1838). In his early compendium book "*Infusionsthierchen*", Ehrenberg (1838) described the morphology, growth habit and ecology of the genus in French and Latin. The name of the genus is derived from its growth habit, adnate on filamentous algae. *Cocconeis* Ehrenberg is a monoraphid diatom genus widely distributed in marine and freshwater environments, with more than 200 described species, with the main taxa being marine species (Guiry 2023; Kociolek et al. 2023). The frustules of this genus are heterovalvar, with one raphe valve (RV) and one rapheless or sternum valve (SV), where the former is typically less convex than the latter (Jahn et al. 2009; Stancheva 2018; Mora et al. 2022). Solitary cells of *Cocconeis* are attached to filamentous algae or other substrates by their RV, while the SV is exposed to the environment. Valves of *Cocconeis* are elliptical or slightly linear-elliptical in shape and this genus has distinctly different areolae structures on both valves (Round et al. 1990). The areolae of the RV are fine and often have a semicircular hyaline area near the valve ends, while the areolae of the SV are

relatively coarse extending to the valve edge and lacking a hyaline area. Striae are usually uniseriate in freshwater species and the poroids are closed by hymenes (Costa et al. 2020). The frustule structure of *Cocconeis* is diverse and complex, species delineation requires detailed observations of the RV morphology, the SV and their connecting elements including valvocopulae and the cingulum (Potapova and Spaulding 2013; Stancheva 2022).

In China, 18 freshwater *Cocconeis* taxa have been recorded, including ten species and eight varieties (Skvortsov 1935; Chin 1951; Zhu and Chen 1989, 1994, 2000; Lin and Wang 1992). China remains a poorly-researched area, with few studies of this genus having gained the attention of researchers. In recent years, we conducted an extensive biodiversity investigation of monoraphid diatoms in China and one new *Cocconeis* species was found, which is distributed in the Qingyi River and Maolan Nature Reserve. This paper describes the frustule morphological characteristics of *C. crisscrossis* sp. nov. using LM and SEM and compares this new species with similar species of the genus.

Materials and methods

Diatom samples were collected from two sites: Qingyi River (Yi County, Anhui Province) and Maolan Nature Reserve (Libo County, Guizhou Province). Samples were collected using tweezers or turkey baster. The samples were preserved using formalin solution before being stored in sealed plastic bottles. Sample information is listed in Table 1, including location of samples, longitude and latitude, habitat, pH, conductivity and collection date.

In the laboratory, the samples were processed with concentrated nitric acid using the Microwave Accelerated Reaction System (Model MARS, CEM Corporation, Charlotte, USA); the specific processing and observation steps are described in You et al. (2021). Images were compiled with Adobe Photoshop 2023. Morphological terminology follows Donadel et al. (2018) and Riaux-Gobin et al. (2021). The holotype image of the single specimen is a circled specimen on the type slide. The samples and permanent slides are preserved in Lab of Algae and Environment, College of Life Sciences, Shanghai Normal University.

Table 1. Locality data and habitat for samples studied.

No. of samples	Location	Coordinates	Habitat	K[μs/cm]	pH	Collection Date
QYJ201710Z12	Qingyi River	30°09'03"N, 117°53'28"E	Attached to stones in the stream	120	8.5	10.1.2017
GZ201510042	Maolan Nature Reserve	25°27'48"N, 107°69'19"E	Attached to stones in the pond	305	7.5	10.2.2015
GZ201510057	Maolan Nature Reserve	25°24'72"N, 107°70'19"E	Attached to floating material near the waterfall	297	7.5	10.2.2015
GZ201510064	Maolan Nature Reserve	25°25'08"N, 107°71'13"E	Attached to stones near the waterfall	297	8.0	10.4.2015
GZ201510088	Maolan Nature Reserve	25°15'71"N, 108°14'22"E	Attached to stones in the stream	296	8.2	10.4.2015
GZ201510096	Maolan Nature Reserve	25°15'74"N, 108°04'18"E	Attached to stones near the waterfall	271	8.2	10.4.2015
GZ201510103	Maolan Nature Reserve	25°17'23"N, 108°04'26"E	Attached to mosses in the stream	272	7.8	10.4.2015

Results

***Cocconeis crisscrossis* Q.M. You, P. Yu, J.P. Kociolek & Q.X. Wang, sp. nov.**

Figs 1A–X, 2A–F, 3A–E, 4A–F, 5A–C, 6A–C

Holotype(designated here). SHTU! slide QYJ201710Z12, holotype illustrated in Fig. 1D, J. Diatom samples are housed in the Lab of Algae and Environment, College of Life Sciences, Shanghai Normal University, China.

Type locality. CHINA. Qingyi River, Anhui Province, 30°9'3"N, 117°53'28"E, collected by Q.X. Wang & P. Yu, 1 October 2017.

Description. Light microscopy (LM) (Fig. 1A–X). Valve elliptical to slight round-elliptical, apices are obtusely rounded; 12.5–42.0 µm long, 9.5–25.0 µm wide. The number of striae on both valves is similar, with parallel orientation at the centre and radiate towards the apices. Both valves display striae with a density of 18–22 rows per 10 µm. Raphe valves (RV) have a thickened hyaline rim on the margin and striae composed of small, nearly round areolae. The raphe is straight, the axial area is narrow, the central area is irregularly narrow, cuniform and the axial area and central area form an irregular cross-like structure. Sternum valve (SV) areolae are rounded and form 7–9 undulating longitudinal lines per hemivalve (increasing in number with increased valve width). The sternum is narrow, linear. The valvocopula has irregularly-spaced digitate fimbriae.

Scanning electron microscopy (SEM) (Figs 2–6) shows RV face is flat with a weakly concave mantle and very narrow linear axial area; the central area extends irregularly to both sides (Figs 3A–C, E, 4A–D). Externally, the raphe is straight, filiform and proximal raphe endings are slightly drop-like and expanded (Fig. 3E). Internally, the proximal raphe fissures are bent to opposite sides (Fig. 4D); the distal raphe endings are straight and end in weakly-elevated helictoglossae on the hyaline rim (Fig. 4E). Striae are made up of round to slightly elliptical uniseriate areolae which are small and regularly spaced, increasing in size from the axial area towards the valve margin and the apices (Fig. 3A–C). Internally, the areolae are occluded by round lattice-structured hymens with short slits around the margin and tiny perforations in the middle (Fig. 4F). SV has a narrow and straight sternum (Fig. 5A, B). In the SEM, it can be seen that, on the SV, the areolae differ greatly between the internal and the external sides (Figs 5C, 6C). Externally, striae are composed of irregular, variably-sized and mostly round areolae, differentiated to the valve edge (Fig. 5A). Areolae are occluded by lattice-structured hymens of marginal slits (Fig. 5C). Internally, the areolae are like puncta. There is a linear and straight axial area (Fig. 6A). Valvocopulae with well-developed digitate fimbriae on both valves are characteristics typical of the *C. crisscrossis*, which are close and heavily silicified fimbriae which seem to be attached to the hyaline rim and are irregularly spaced (Fig. 2A–F). The poles of valvocopulae possess unique ‘sword-shaped’ siliceous extensions that extend towards the interior of the valve and may vary in length (see arrows in Fig. 2A–F).

Etymology. Species was named for its crisscross-shaped central area of the raphe valve.

Distribution and ecology. So far, the new species has been collected at Qingyi River and Maolan Nature Reserve. The Qingyi River population of the

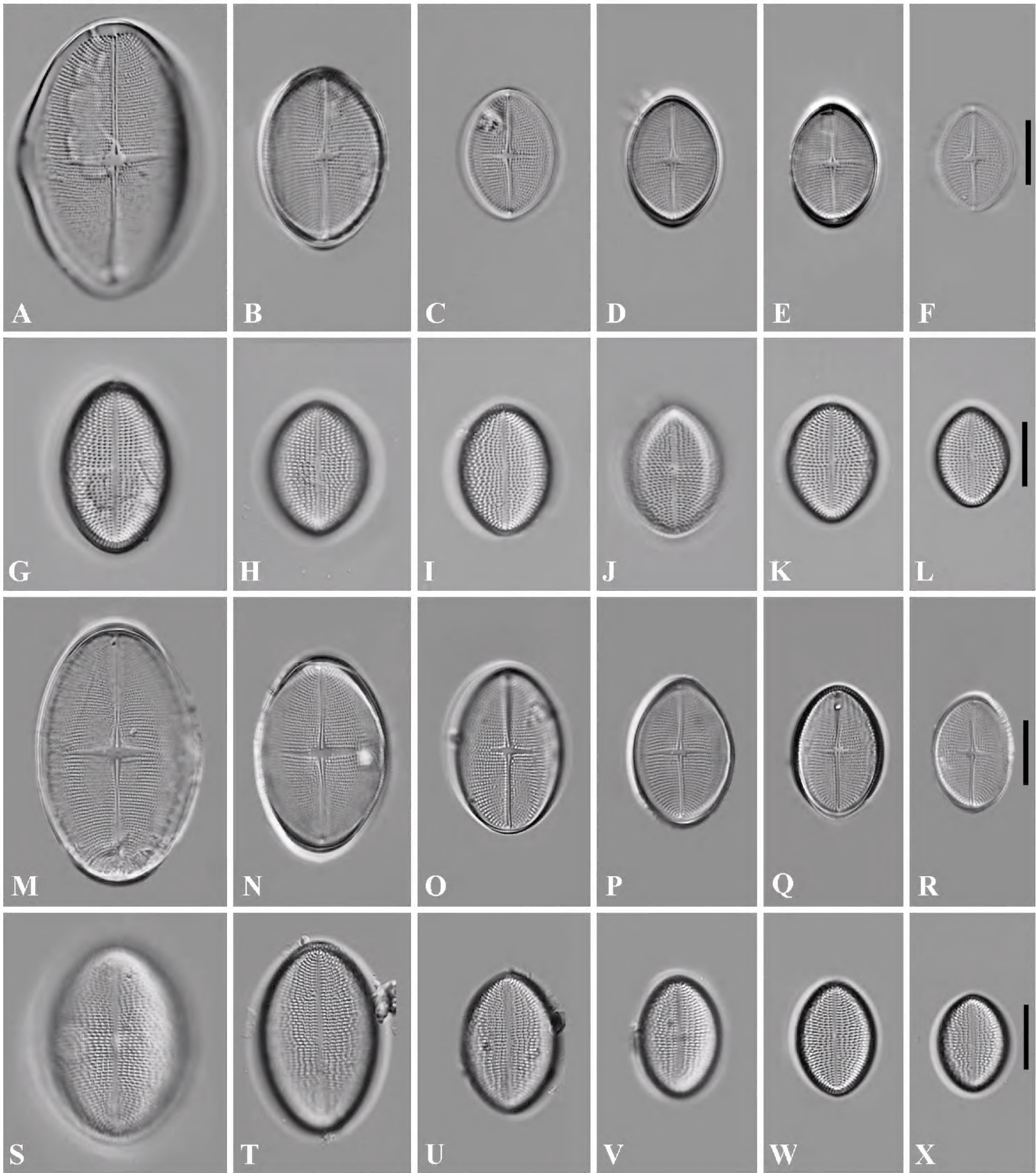


Figure 1. **A–L** Light micrographs of *Cocconeis crisscrossis* sp. nov. from Qingyi River **M–X** light micrographs of *C. crisscrossis* sp. nov. from Maolan Nature Reserve **A–F, M–R** raphe valves(RV) **G–L, S–X** sternum valves (SV). Scale bars: 10 μ m (**A–X**).

new species appears to have a higher abundance in that location than populations from the Maolan Nature Reserve. The habitat of the new species is characterised by circumneutral to alkaline pH (7.5–8.5) and conductivity (120–305 μ s/cm) and temperature range 18.0–24.0 $^{\circ}$ C.

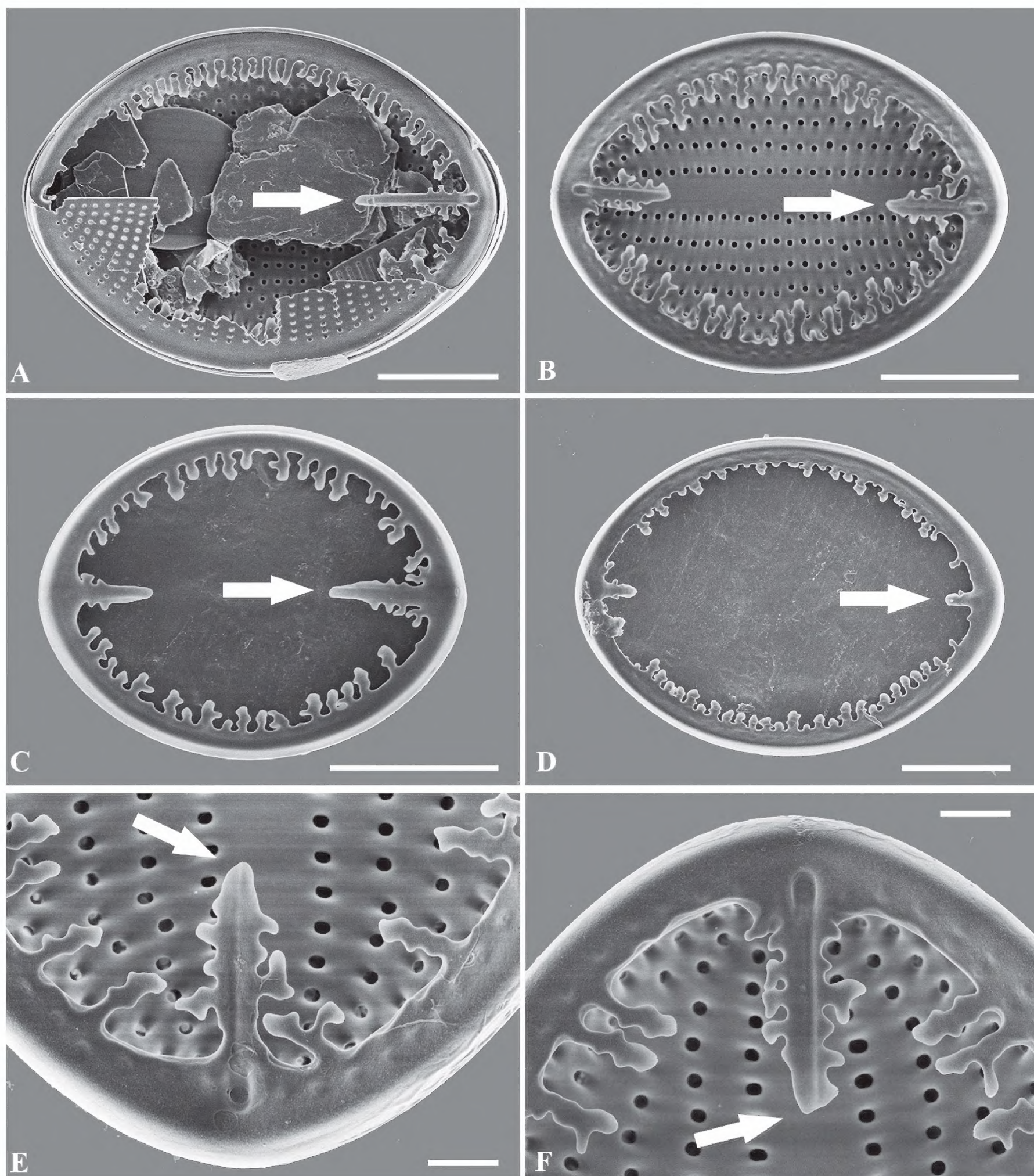


Figure 2. A–F SEM micrographs, the valvocopula of *C. crisscrossis* sp. nov. from Qingyi River with well-developed digitate fimbriae, which is close and heavily silicified clamp-like fimbriae seem to be attached to the hyaline rim and are irregularly spaced; the poles of valvocopulae possess unique ‘sword-shaped’ siliceous extensions (arrows in A–F) A valvocopula of the RV B–F valvocopula of the SV. Scale bars: 5 µm (A–D); 1 µm (E, F).

Discussion

The morphological differences between species of *Cocconeis* are limited (Stancheva 2022). *Cocconeis crisscrossis* sp. nov. was compared with other related species (e.g. *C. pediculus* Ehrenberg, *Cocconeis chernobyliensis* Genkal, Shcherbak & Semenyuk and *C. molesta* Kützing) which are structurally similar

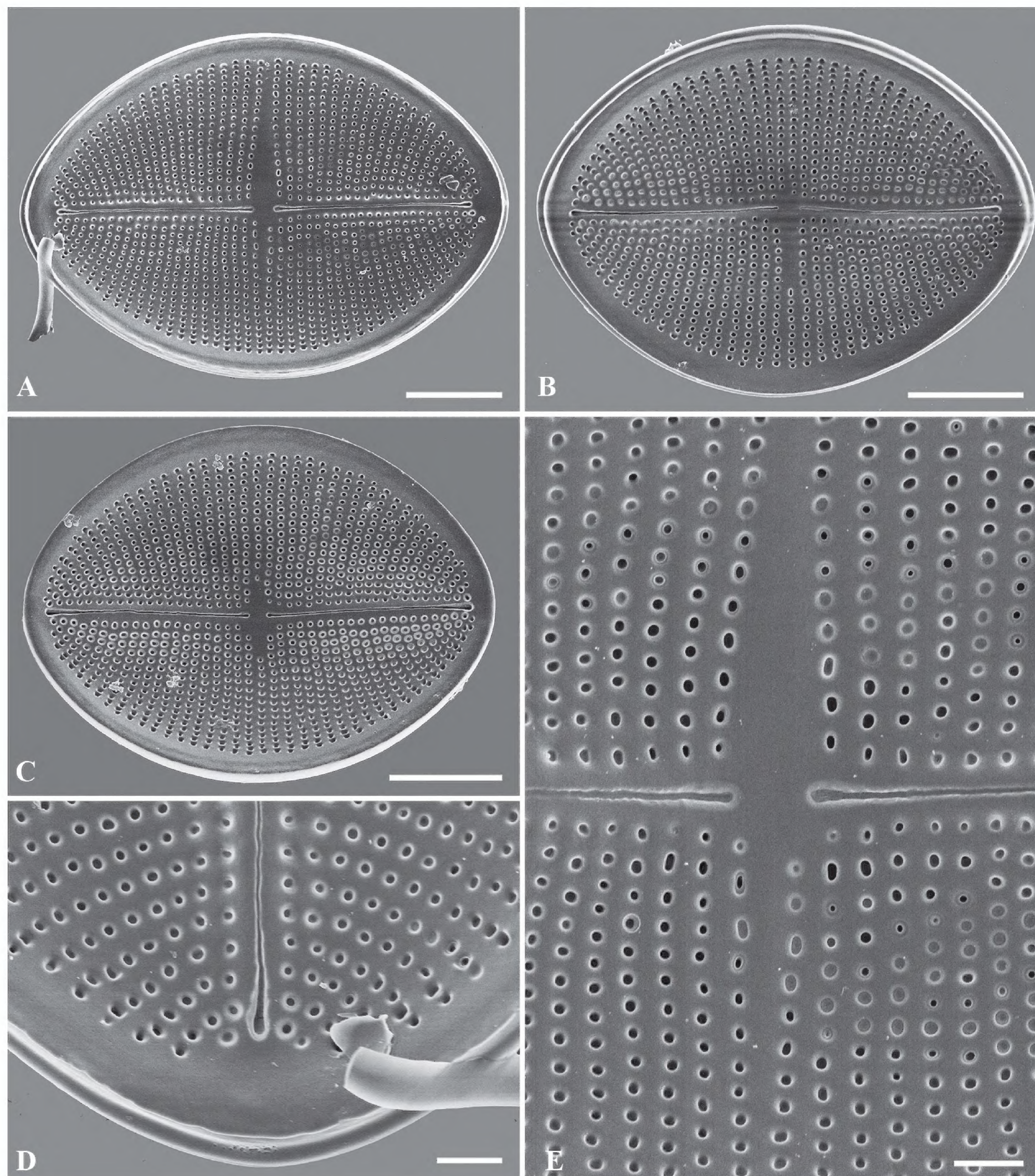


Figure 3. **A–E** SEM micrographs, RV external views of *C. crisscrossis* sp. nov. from Qingyi River **A–C** complete internal valve **D** proximal raphe endings are slightly drop-like expanded **E** irregular hyaline central area. Scale bars: 5 µm (**A–C**); 1 µm (**D, E**).

under the light microscope: they all have an elliptical valve outline, concave valve curvature, as well as the size and the arrangement of the striae which are almost parallel in the centre, radiate and slightly curved towards the apices. While the most obvious differences are mainly with respect to the central area under the light microscope. The central area of *C. crisscrossis* sp. nov. extends irregularly to both sides. That feature is absent or not as distinct in morphologically similar taxa. It is one characteristic that distinguishes our new species from other similar species (Table 2).

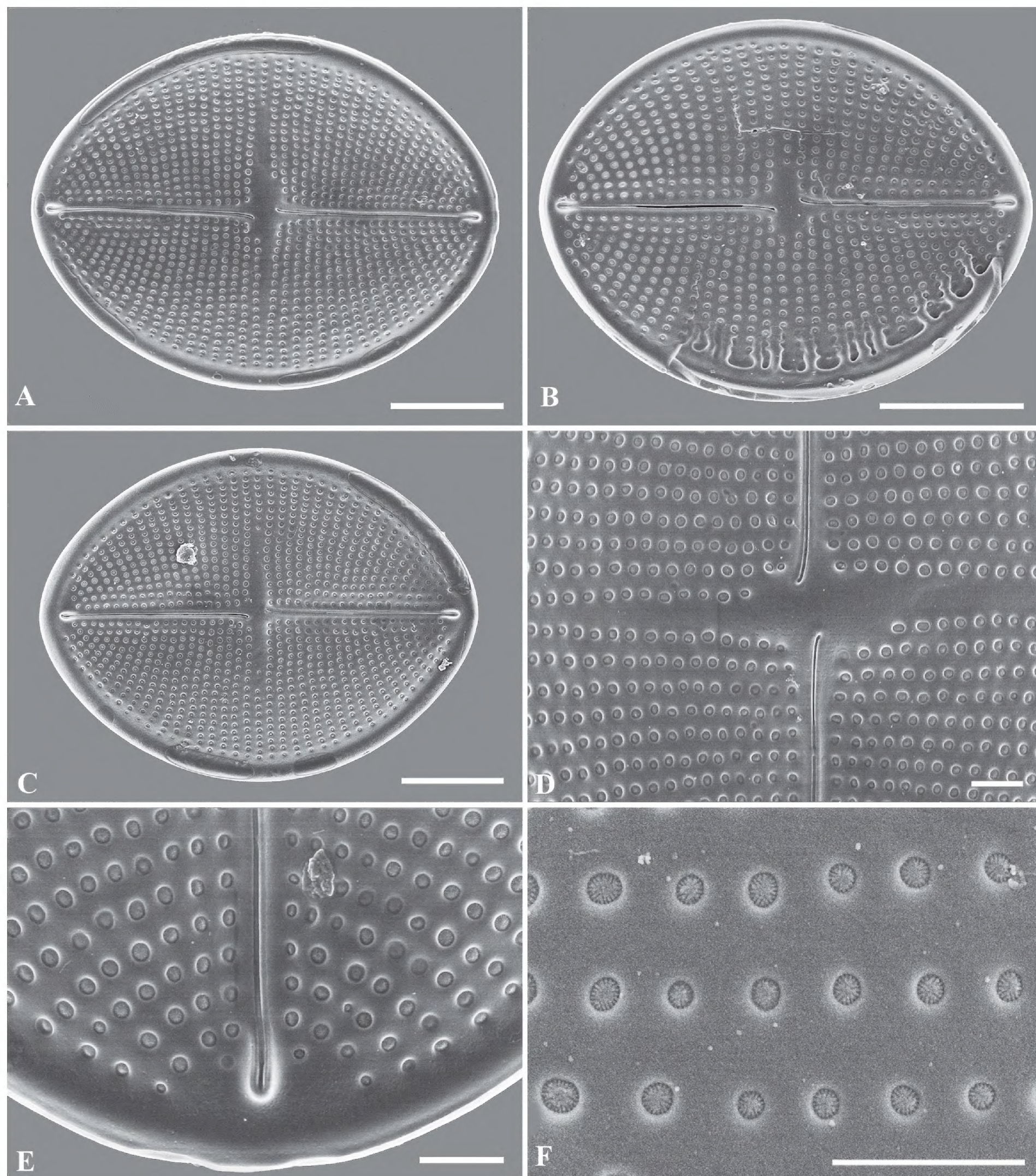


Figure 4. A–F SEM micrographs, RV internal views of *C. crisscrossis* sp. nov. from Qingyi River A–C complete internal valve D irregular hyaline central area and the proximal raphe fissures are bent to opposite sides E weakly elevated helictoglossae F the areolae are occluded by round lattice-structured hymens. Scale bars: 5 µm (A–C); 1 µm (D–F).

The morphology of the RV, the SV and their connecting elements, such as the valvocopulae and the cingulum, are essential for delimiting species within the genus (Riaux-Gobin et al. 2013; Stancheva 2022). The valvocopula system and arrangement show significant variation amongst *Cocconeis* taxa, ranging from intricate fimbriae to no ornamentation; however, the morphology of the valvocopulae is thought to be diagnostic for each taxon (Holmes et al.

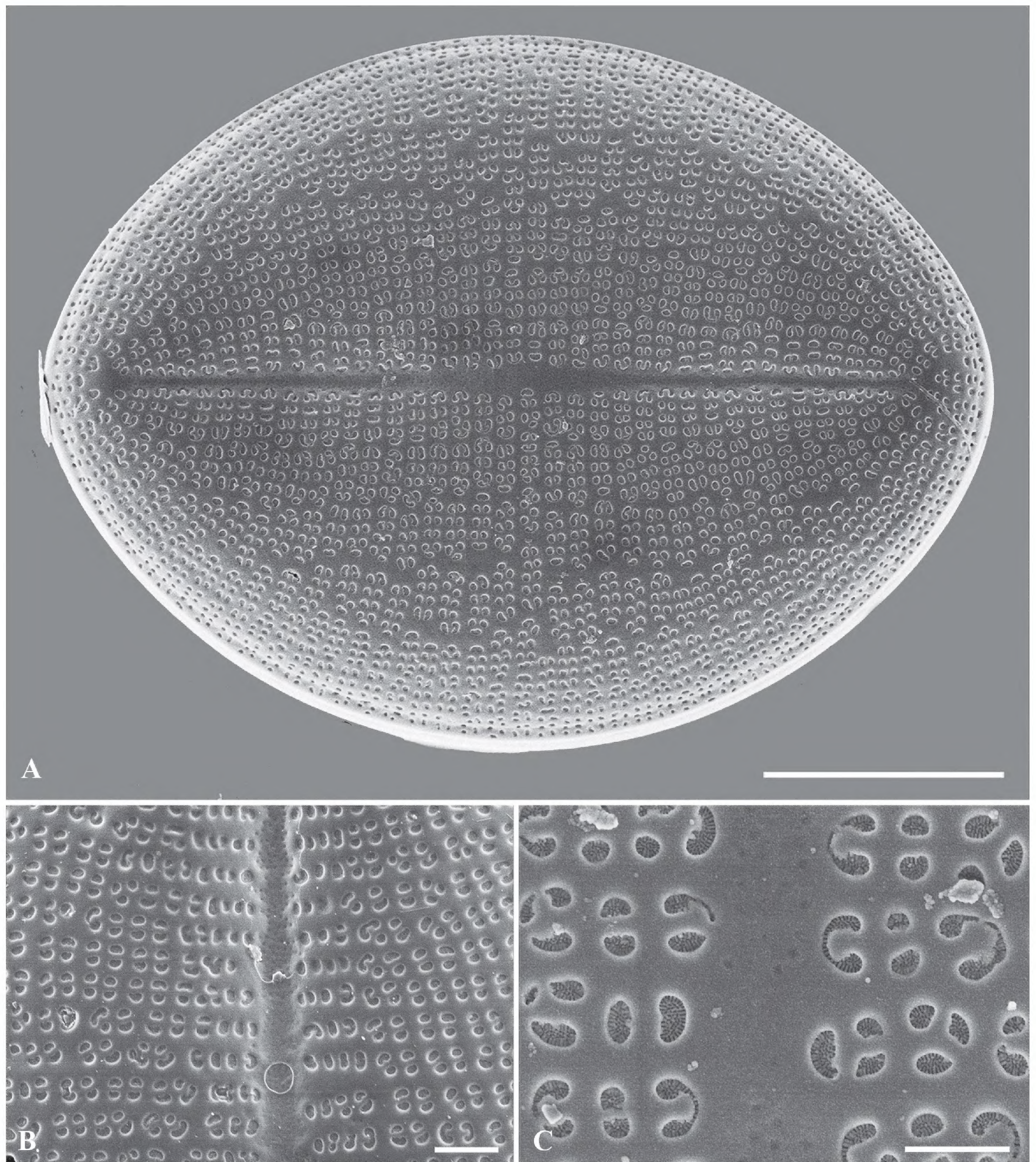


Figure 5. A–C SEM micrographs, SV external views of *C. crisscrossis* sp. nov. from Qingyi River **A** complete internal valve **B** narrow and straight sternum **C** Irregular areolae are occluded by lattice-structured hymens. Scale bars: 5 μm (**A**); 1 μm (**B**); 0.5 μm (**C**).

1982; Kobayasi and Nagumo 1985; Round et al. 1990; Riaux-Gobin et al. 2021; Stancheva 2022). As shown in Table 2, *C. crisscrossis* was compared with three similar taxa which are structurally different in ultrastructure, mainly in the valvocopulae. *Cocconeis crisscrossis* and *C. pediculus* possess close valvocopulae with fimbriate margins, while the fimbriae margins of *C. pediculus* are short and present only in the central part of the valve, never at the poles. In contrast

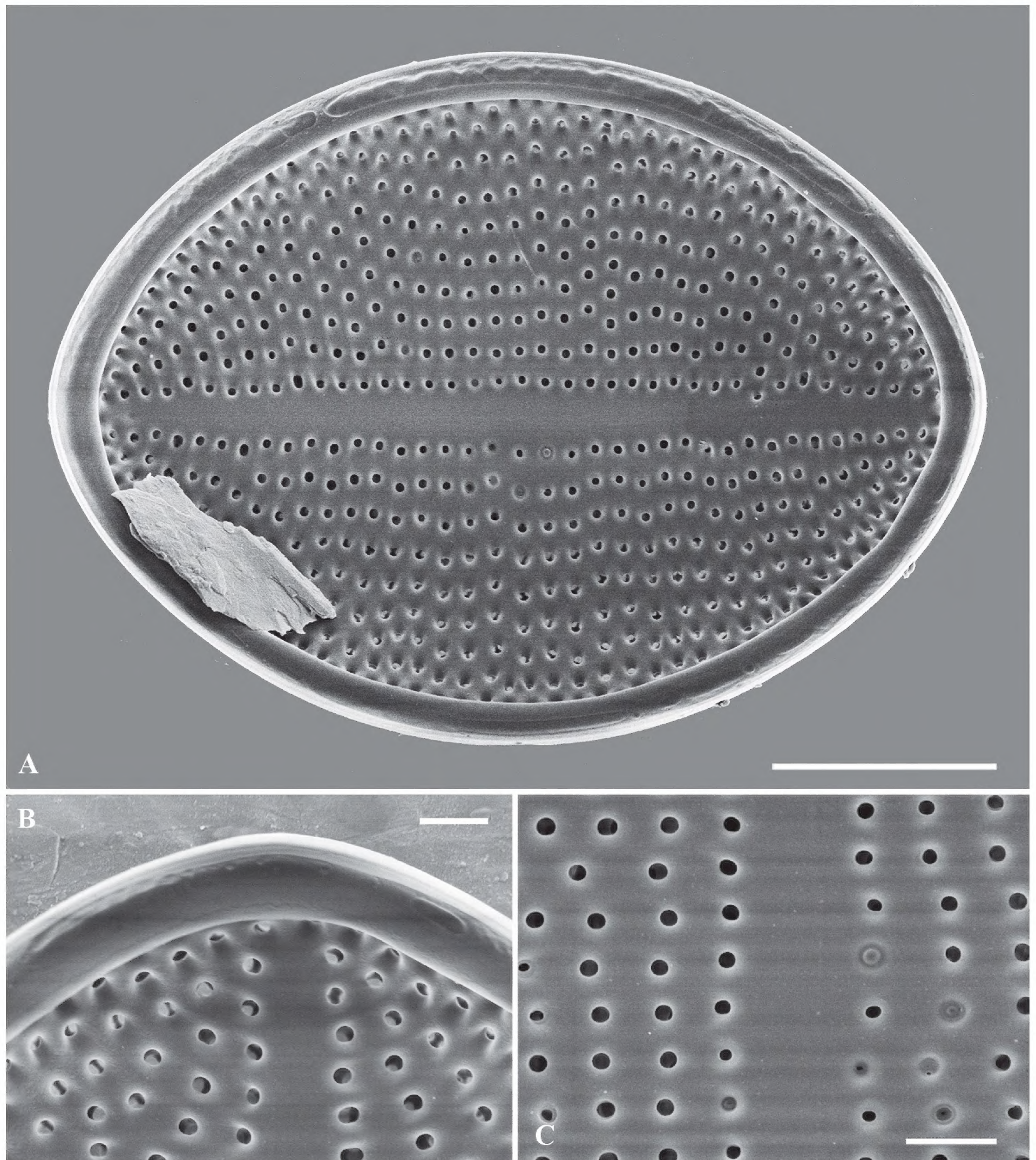


Figure 6. A–C SEM micrographs, SV internal views of *C. crisscrossis* sp. nov. from Qingyi River **A** complete internal valve **B, C** detail of the internal valves ends. Scale bars: 5 μm (**A**); 1 μm (**B, C**).

to this, valvocopulae of *C. crisscrossis* surround the entire valve, which has longer fimbriae of uneven length and the poles of valvocopulae have distinct ‘sword-shaped’ siliceous extensions towards the interior of the valve, which vary in length, likely owing to different developmental stages. *C. crisscrossis* and *C. pediculus* exhibit remarkable morphological similarity, as both have closed valvocopulae and lack a submarginal hyaline area. These morphological similarities may indicate a close affinity between the two species.

Table 2. Comparison of morphological characteristics of *Cocconeis crisscrossis* sp. nov. and closely-related taxa.

	<i>Cocconeis crisscrossis</i> sp. nov.	<i>Cocconeis pediculus</i>	<i>Cocconeis chernobyliensis</i>	<i>Cocconeis molesta</i>
Reference	This study	Jahn et al. (2009)	Genkal et al. (2022)	Riaux-Gobin et al. (2016)
Valve outline	Elliptical	Elliptical to somewhat rhombic-elliptical	Elliptical-lanceolate	Elliptical
Length (µm)	12.5–42.0	(11)13.5–40.0(56)	20–36.5	16.4
Width (µm)	9.5–25.0	(6)11.8–26.5(37)	16.5–28.9	9.1
Valvocopulae (RV and SV)	Close, with fimbriate margins, poles have extensions	Close, fimbriate margins in the central part of the valve	Nd	Nd
Central area (RV)	Irregular extends to submarginal to form a cross structure	Small, more or less oval	Narrow, well developed	Narrow, and half a valve in length
Raphe distal endings (RV)	Straight	Straight	Straight	Deflected
Striae (RV)	18–22/10 µm	14–22(24)/10 µm	11–18/10 µm	ca. 30/10 µm
Striae (SV)	18–22/10 µm	14–22(24)/10 µm	12–17/10 µm	40–42/10 µm

During our observation of this new species, we have discovered that the fimbriate margins of the valvocopula, which occur in the central part of the valve, display considerable morphological stability, while the size and length of the fimbriae exhibit variation. In addition, the size and length of the ‘sword-shaped’ siliceous extensions at the end of valvocopula also vary.

Acknowledgements

We are grateful for the comprehensive comments from reviewers and the editor in relation to scientific aspects, format and language.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Funding

This research was funded by the Natural Science Foundation of Shanghai (No.21ZR1447300).

Author contributions

All authors have contributed equally.

Author ORCIDs

Pan Yu  <https://orcid.org/0000-0001-7937-2381>
John Patrick Kociolek  <https://orcid.org/0000-0001-9824-7164>
Qingmin You  <https://orcid.org/0000-0002-5538-8503>

Data availability

All of the data that support the findings of this study are available in the main text.

References

- Chin TG (1951) A list of Chinese diatoms from 1847–1946, Amoy fisheries bulletin 1(5): 41–143.
- Costa LF, Wetzel CE, Ector L, Bicudo DC (2020) Freshwater *Cocconeis* species (Bacillariophyceae) from Southeastern Brazil, and description of *C. amerieuglypta* sp. nov. Botany Letters 167: 15–31. <https://doi.org/10.1080/23818107.2019.1672103>
- Donadel L, Torgan L, Al-Handal A (2018) Additional morphological features of the epiphytic diatom *Cocconeis sawensis* Al-Handal and Riaux-Gobin (Cocconeidaceae, Bacillariophyta) from a coastal lagoon, Southern Brazil. Phytotaxa 371(3). <https://doi.org/10.11646/phytotaxa.371.3.5>
- Ehrenberg CG (1838) Die Infusionsthierchen als vollkommene Organismen. Ein Blick in das tiefere organische Leben der Natur. Leopold Voss, Leipzig, 548 pp. <https://doi.org/10.5962/bhl.title.58475>
- Genkal SI, Shcherbak VI, Semenyuk NY (2022) On representatives of diatoms (Bacillariophyta) new for science from the exclusion zone of the Chernobyl nuclear power plant (Ukraine). Inland Water Biology 15(4): 501–505. <https://doi.org/10.1134/S1995082922040290>
- Guiry MD (2023) AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. <https://www.algaebase.org> [searched on 13 November 2023]
- Holmes RW, Crawford RM, Round FE (1982) Variability in the structure of the genus *Cocconeis* Èhr. (Bacillariophyta) with special reference to the cingulum. Phycologia 21(3): 370–381. <https://doi.org/10.2216/i0031-8884-21-3-370.1>
- Jahn R, Kusber W, Romero OE (2009) *Cocconeis pediculus* EHRENBERG and *C. placentula* EHRENBERG var. *placentula* (Bacillariophyta): Typification and taxonomy. Fottea 9: 275–288. <https://doi.org/10.5507/fot.2009.027>
- Kobayasi H, Nagumo T (1985) Observations on the valve structure of marine species of the diatom genus *Cocconeis* Ehr. Hydrobiologia 127(2): 97–103. <https://doi.org/10.1007/BF00004189>
- Kociolek JP, Blanco S, Coste M, Ector L, Liu Y, Karthick B, Kulikovskiy M, Lundholm N, Ludwig T, Potapova M, Rimet F, Sabbe K, Sala S, Sar E, Taylor J, Van de Vijver B, Wetzel CE, Williams DM, Witkowski A, Witkowski J (2023) DiatomBase. <http://www.diatombase.org>
- Lin BQ, Wang JX (1992) A preliminary study on diatoms of spring and early summer in Qianshan mountains, Liaoning province. Journal of Liaoning Normal University 15(3): 234–239.
- Mora D, Stancheva R, Jahn R (2022) *Cocconeis czarneckii* sp. nov. (Bacillariophyta): A new diatom species from Lake Okoboji (Iowa, USA), based on the strain UTEX FD23. Phycologia 61(1): 60–74. <https://doi.org/10.1080/00318884.2021.2003684>
- Potapova M, Spaulding S (2013) *Cocconeis placentula* sensu lato. In Diatoms of the United States. http://westerndiatoms.colorado.edu/taxa/species/cocconeis_placentula [Retrieved January 01, 2022]
- Riaux-Gobin C, Romeron OE, Coste M, Galzin R (2013) A new *Cocconeis* (Bacillariophyceae) from Moorea Island, Society Archipelago, South Pacific Ocean with distinctive valvocopula morphology and linking system. Botanica Marina 56(4): 339–356. <https://doi.org/10.1515/bot-2012-0162>

- Riaux-Gobin C, Compère P, Jordan RW, Coste M, Yesilyurt JC (2016) *Cocconeis molestata* Kütz., *C. diaphana* W.Sm. and *C. dirupta* W.Greg. (Bacillariophyta): Type material, ambiguities and possible synonymies. *European Journal of Taxonomy* 204: 1–18. <https://doi.org/10.5852/ejt.2016.204>
- Riaux-Gobin C, Frankovich T, Witkowski A, Saenz-Agudelo P, Esteve P, Ector L, Bemiasa J (2021) *Cocconeis tsara* sp. nov., *C. santandrea* sp. nov. and allied taxa pertaining to the new section Loculatae. *Phytotaxa* 484(2): 145–169. <https://doi.org/10.11646/phytotaxa.484.2.1>
- Round FE, Crawford RM, Mann DG (1990) *The Diatoms: Biology and Morphology of the Genera*. Cambridge University Press, Cambridge, 747 pp. <https://doi.org/10.1017/S0025315400059245>
- Skvortsov BV (1935) Diatomées récoltées par le Père E. Licent au cours de ses voyages dans le Nord de la Chine au bas Tibet, en Mongolie et en Mandjourie. *Publications du Musée Hoangho Paiho de Tien Tsin* 36: 1–43.
- Stancheva R (2018) *Cocconeis cascadiensis*, a new monoraphid diatom from mountain streams in Northern California, USA. *Diatom Research* 33: 471–483. <https://doi.org/10.1080/0269249X.2019.1571531>
- Stancheva R (2022) *Cocconeis fetscheriana* sp. nov. (Bacillariophyta) from streams in California (USA) with reference to the cingulum variability within the placentuloid species complex. *Diatom Research* 37: 127–144. <https://doi.org/10.1080/0269249X.2022.2074145>
- You QM, Zhao K, Wang Y, Yu P, Kociolek P, Pang WT, Wang QX (2021) Four new species of monoraphid diatoms from Western Sichuan Plateau in China. *Phytotaxa*. <https://doi.org/10.11646/phytotaxa.479.3.3>
- Zhu HZ, Chen JY (1989) The Diatoms of the Suoxiyu Nature Reserve Area, Hunan, China. In: Li SH, et al. (Eds) *The algal flora and aquatic fauna of the Wulingyuan Nature Reserve Area, Hunan, China*. Science Press, Beijing, 38–60.
- Zhu HZ, Chen JY (1994) Study on the Diatoms of the Wuling Mountain Region. In: Shi Z X et al. (Ed.) *Compilation of Reports on the Survey of Algal Resources in South-Western China*. Science Press, Beijing, 79–130.
- Zhu HZ, Chen JY (2000) *Bacillariophyta of the Xizang Plateau*. Science Press, Beijing, 353 pp.